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# Performance and listener preference of four mobile phone-to-hearing aid interface units

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### Abstract

*Speaking on the telephone is one of the most commonly reported difficulties faced by the hearing impaired. Mobile telephones provide a further problem as they are designed to be used 'on the go', and are therefore often used in noisy environments. To address this issue, both hearing aid and mobile phone companies have produced devices that aim to improve the mobile phone experience in the hearing impaired. The study reported here offers an impartial assessment of the efficiency of four of these units; Starkey's ELI, Phonak's Smartlink and iCom, and the Artone. Consonant-Vowel-Consonant word recognition and user satisfaction were measured in both quiet and in presence of background noise, and the Smartlink was determined to be the most effective device. It was, however, considerably more expensive than the other devices on test, and this should be taken into account when recommending a device to a client.*

## 1. Introduction

In 2007, Reuters announced that the world penetration of mobile phones had reached 50%, and that in some Western countries, penetration was over 100% [1]. These figures emphasise the importance of mobile phones in modern life, and show how at least half of the world's population is accustomed to the instant, 'always available' status that these devices offer. Unfortunately, this integral aspect of modern life was often denied to the hearing impaired community, as functionality with hearing aids and cochlear implants was hindered by the electromagnetic or radio frequency interference that the phones emit [2]. These problems still exist, but have decreased in recent years due to improved technologies, such as digital signal processing, which have increased the resistance of hearing aids to RF interference [3], and governmental obligations, such as those of the Federal Communications Commission (FCC) in the USA, towards compatibility between hearing aid and mobile phone [3-5].

Regrettably, technical problems are not the only issues faced by hearing impaired listeners wishing to use mobile phones, as hearing aid users often have difficulty communicating over the telephone relative to face to face speech [6]. Primarily, the lack of visual cues when using a phone removes crucial information from the speaker which is particularly important for the hearing impaired. New 3G technology is available, which allows a speaker to be seen as well as heard, but 3G phones are expensive, the number of people carrying a compatible phone and who are willing to make a video call, and the 3G connectivity are disfavourable [7]. The limited bandwidth of phones also contributes to the reduced intelligibility. Both landline and cell phones generally have bandwidths which range between approximately 300 to 3500Hz [8], and therefore important high frequency cues in speech are lost. Furthermore, mobile phones, by their nature, are to be used when 'on the go' and as a result the user could be in a noisy environment when a call is received. Background noise is recognised as a major factor influencing hearing aid satisfaction [9]; it therefore makes sense that hearing on a mobile phone in noise will be difficult. Considering that the acoustic output level of a phone is sometimes not loud enough for some hearing aid users [8] the signal-to-noise ratio in a noisy environment could be very low. This means that hearing aid users receive calls but the speech signal may be masked by background noise.

## 1.1. Improvements in hearing aid/mobile phone compatibility

Neck loops are a commercially available product specifically designed for hearing aid users that have problems communicating using mobile phones [10, 11]. They consist of a wire loop worn around the individual's neck and connected to the mobile phone. Upon receiving a signal from the mobile, the loop relays this signal to the hearing aids via an induction loop, using the telecoil contained within the aid. As such, only hearing aids with telecoils are compatible with a neck loop, which limits their usage to larger hearing aids (mainly Behind-The-Ear; BTE). Many hearing aids have the option to turn off the hearing aid microphone while using a neck loop, reducing and acoustic input and, as a result, any unwanted background noise. Sorri et al. [10] investigated the effectiveness of Nokia Loopsets and found promising results. Unfortunately loopsets are connected directly to the phone via a cable and require a specific connector, normally a 2.5mm stereo jack. Many phones on the market no longer have a 2.5mm stereo output and therefore using a neck loop severely limits the choice of phone for hearing aid users. These devices also have the disadvantage that the signal can be affected by electromagnetic noise. More recently, the advent of Bluetooth and other wireless technology has allowed more solutions to be developed.

Bluetooth Wireless technology was originally developed in 1994 by Ericsson, but it wasn't until 1998 that many other companies joined to form the Bluetooth Special Interest Group (SIG), which aimed to develop the technology as a replacement for connecting cables [12]. Bluetooth is a short range (1-10m) wireless area networking method, designed to allow connectivity between personal equipment (such as mobile phones or digital cameras) to larger networks of computers and equipment. The name 'Bluetooth' is an anglicised version of the name of the 10$^{th}$ century Danish/Norse king, Harald Blåtand, who is renowned for uniting the Scandinavian people. The implication is that Bluetooth unites hardware with similar efficiency [12].

Of the 1.2 billion cellular handsets introduced into the market in 2008, over half had Bluetooth capability [13]. In recent years, hearing aid manufacturers (e.g. Starkey, Phonak, Siemens and Oticon) and mobile phone producers (e.g. Nokia) have attempted to harness this inclusion to improve mobile phone experience in individuals with hearing aids. Due to the high power consumption and the size required, efforts have not been successful in incorporating Bluetooth directly into the hearing aids [14], and rely therefore on an external device to relay the information from the phone to the hearing aids.

Two of the first of the hearing aid-compatible Bluetooth assisted listening devices (ALDs) were the Starkey ELI (Ear Level Instrument) and the Phonak Smartlink. The ELI uses Bluetooth to send the audio signal from the mobile phone to a device attached to the direct audio input (DAI) of a BTE hearing aid, but can also be fitted into a neck loop [11]. The Eli is the only device that receives a Bluetooth signal at the hearing aid, instead of via a intermediary routing device. The Smartlink uses a different approach; instead of a direct connection to the aid, the Smartlink acts as a relay station between the phone and the hearing aid. The mobile phone connects to the Smartlink with Bluetooth, but the Smartlink communicates with both aids with a FM signal enabling binaural hearing on the phone. The hearing aid must have a FM receiver for the Smartlink to work which again limits the user to BTE hearing aids [14]. A further 'relay station' device comes in the form of the Artone. This device is worn around the neck, as a neck loop, but receives input from the mobile phone via Bluetooth and passes the signal to the hearing aids via induction to the telecoil in the hearing aid. Three more 'relay station' type devices are now on the market, the Phonak iCom, Seimens Tek and Oticon Streamer. These three devices all use Bluetooth to communicate with the mobile and then split the signal before sending it to each hearing aid in discrete streams, so as to provide binaural listening. These devices use digital magnetic transmission, which was introduced by Seimens, with ear to ear wireless technology to enable communication of settings (volume, programs) made to one aid across to the other hearing aid [14]. Digital magnetic transmission, or more specifically near-field magnetic induction communication (NFMIC), differs from wireless communications in that it does not use an antenna and is intended for very short range (ie. 1.5m). T coil technology mentioned earlier also uses magnetic induction except a telecoil signal has no carrier frequency. For telecoils, the signal is directly amplified by the hearing aid, NFMIC has a carrier signal with enough bandwidth to transmit an audio signal. Despite the obvious importance of mobile phone use for hearing aid users, little independent research has been undertaken to evaluate the relative merits of different assistive devices.

The study reported here aimed to offer an impartial comparison of iCom, Artone, Eli, Smartlink units. It was hypothesised that performance would be better in quiet than noise and the performance with ALDs would be superior to unassisted hearing and hearing aids alone.

## 2. Methods

The research described was approved by the University of Auckland Human Participants Ethics Committee, and the authors have no financial interest in the outcome of the study.

### 2.1. Participants

Volunteers were recruited from The University of Auckland Hearing and Tinnitus Clinic. Ten individuals (7 male; 3 female, age range 58-78; mean 64.5; std 6.4) served as participants in the study. Participants were in good mental and physical health, and were current open fit hearing aid users. Their sensorineural hearing impairment had to be within the fitting range of a Phonak Exélia M BTE fitted with open fit tubing. All participants had at least 6 months experience with their current aids and used a mobile phone. No monetary reimbursement was given to the participants of this study.

### 2.2. Materials

Participants were fitted with Phonak Exelia M BTE hearing aids. The assisted listening devices used were the Starkey ELI (Ear Level Instrument), Phonak Smartlink and iCom, and Artone's Bluetooth device. Experimental calls were made to a Vodafone NZ Sony Ericsson V630i mobile phone.

### 2.3. Procedure

All evaluations were undertaken at the Audiology Section of The University of Auckland. Prior to testing, each participant underwent a standard audiological testing battery as follows; the external ear of all participants was checked for obstructions with a Welch Allyn™ otoscope. Pure tone audiometry was performed using a GSI 61 clinical audiometer and Telephonics TDH 50P Supraaural earphones, Sennheiser HAD 200 Circumaural earphones, or E.A.R®tone™ 3A insert earphones fitted with adult foam tips. Bone conduction was performed using a B 71 bone conductor. Tympanometry was conducted using a GSI Tympstar middle ear analyser and an appropriate sized rubber probe tip.

The results from the audiometric tests were then used to program the Phonak Exelia M BTE aids bilaterally to each individual to first fit, based on the NAL NL1 prescriptive formula. Each participant was a current open fit hearing aid user, and when possible each participant was fitted with tubing and domes that matched those that they currently used.

The participants' signal-to-noise ratio (SNR) loss was then measured both with and without hearing aids in place using the Quick Speech In Noise (QuickSIN; [15]) test. This test is a list of six sentences with five key words per sentence presented in four-talker babble noise. SNR loss is defined as the increase in signal-to-noise ratio required by a listener to obtain a 50% correct score compared to normal performance. The test sentences were presented to each participant at 60 dB HL at pre-recorded signal-to-noise ratios which decrease in 5 dB steps from 25 dB (very easy) to 0 dB (extremely difficult), to encompass normal to severely impaired performances in noise. Each key word correct translates to a score of one; there are 30 words in total and therefore a maximum total of 30. This total is then subtracted from 25.5 to give the SNR loss, 0-2 dB is normal, 2-7 dB is a mild SNR loss, 7-15 dB is a moderate SNR loss, and > 15 dB is a severe SNR loss.

Four consonant-vowel-consonant (CVC) speech lists were read to the participant with MLV at 65 dB SPL under six conditions: no hearing aids, hearing aids alone, hearing aids on telecoil mode with an iCom, hearing aids on FM mode with a Smartlink, hearing aids with DAI mode with an Eli attached using an appropriate dock, or hearing aids and an Artone. For each condition, four speech lists were read to the subject over the phone; two lists in quiet and two lists in noise (100 talker babble). CVC speech lists were chosen, as they require the subject to hear the words outright. If sentences had been used, then words could be inferred based on context.

The participant was seated in a separate room to the caller, two metres from the two Aiwa SX-NAVH1200 speakers which were used solely for delivering the noise maskers in the 'noise' condition. They were then instructed by the experimenter on the use of the Vodafone Sony Ericsson V630i mobile phone, and, once confident, the testing began. The first two test condition were the same for all participants, beginning with the conventional use of a mobile phone without hearing aids, followed by hearing aids alone without any assistive listening devices (ALD). The participant was instructed to answer the mobile phone provided and hold the phone to their favoured ear as they normally would. Stimuli were presented using monitored live voice. Four consonant-vowel-consonant (CVC) word lists were read into an Ericsson 4220 landline phone from a separate room at a level of 65-70 dB SPL, as measured with a Brüel and Kjær type 2250 hand held analyser positioned at the level of the phone's speaker.

Two lists were first read in quiet and the responses from the participant were scored and recorded, followed by two lists in noise in the same manner. After the lists were complete the participant was asked to rate how well they heard on the phone in quiet and in noise out of ten on a visual analogue scale (VAS; one being poor and 10 being very well) and given an opportunity to make any comments they had. The hearing aids were then worn by the participant and they were instructed on the positioning the mobile phone above the ear over the microphones of the BTE hearing aids. The positioning of the mobile can greatly affect the sound level heard and each participant was given time to find the optimal position for listening on the phone before any speech lists were read. Four further CVC word lists were read to the participant in quiet and noise and two VASs recorded in the same fashion as above. Each participant was instructed on the particular ALD of use, four lists were read, two in quiet and two in noise and two VASs were filled out once the word lists were complete. The order of the remaining four conditions varied for each participant.

### 2.4. Statistical analysis

In order to study the changes in the two measures recorded in this study (Speech and VAS scores), a repeated measures analysis of variance was carried out, with ALD and background situation (Quiet/Noise) as independent factors, and VAS and Speech scores as the dependent variables. This test was carried out using the Repeated Measures General Linear Model function in SPSS 15.

## 3. Results

### 3.1. Hearing thresholds

All ten participants had a high frequency sensorineural hearing loss in both ears, as shown in figure 1. All participants were mobile phone users, but none were familiar with the mobile phone used in this study, and none had used any of the ALDs used in this study before. The quickSIN test revealed that four of the 10 participants did not benefit from wearing a hearing aid for speech comprehension in noise (Fig.2.).

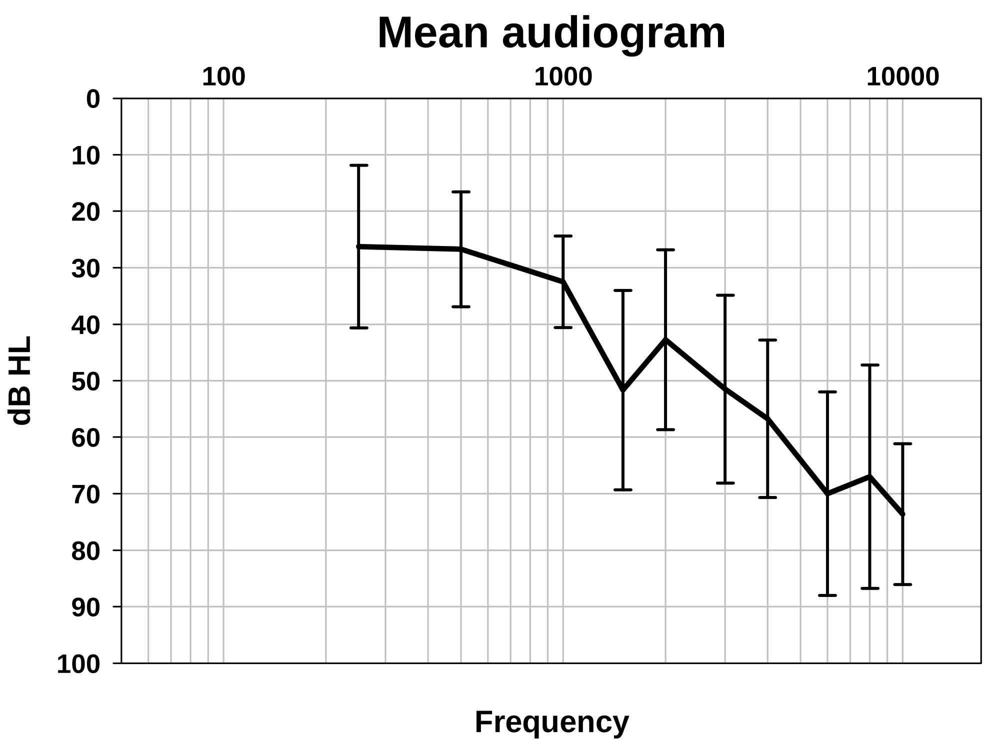


**Figure 1 - Average hearing loss and standard deviation (error bars) across all listeners (both ears).**

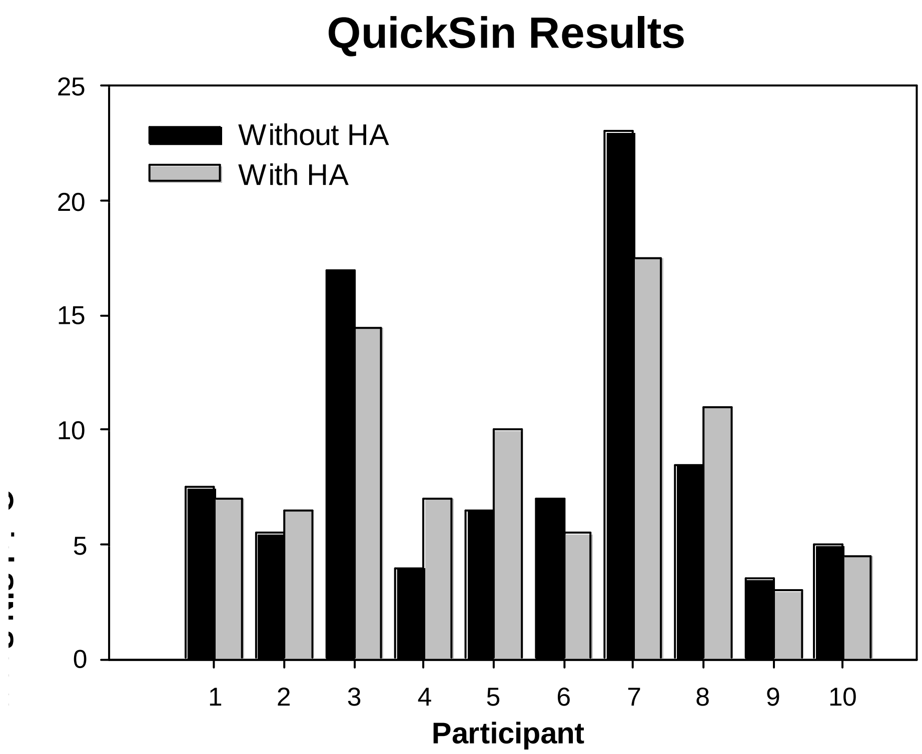


**Figure 2 - Results of the QuickSIN test by participant**

## 3.2. Assisted listening device performance

Subject's performance was tested using each ALD by reading CVC words and making a note of the number of words that were correctly identified by the participant when using the mobile phone under each listening condition (Quiet or Noise; Fig. 3.). The subject's opinion of the performance of the ALD was then determined using a VAS system (Fig.4.). Scores did not vary according to the participant's results in the QuickSIN test (Fig.2).

## 3.3. Comparison of Quiet and Noise performance

As hypothesised, there was a main effect of Background in performance when looking at both Speech and VAS scores ($F_{2, 7} = 43.7$; $p < .001$). In a quiet environment, scores were higher than when the background noise was applied. This was true whether using a hearing aid or not, and whether an ALD was used to assist listening. There was also a main effect of Device (no hearing aid, HA alone, or use of each ALD; $F_{10, 78}= 6.7$; $p < .001$), and a statistically significant interaction between Device and Background ($F_{10, 78}= 4.4$; $p < .001$), suggesting that some ALDs were better in Noise than others. In order to determine these differences, performance will now be described by Background type (either in Quiet or in Noise).

### 3.3.1. Testing in Quiet

Generally, the use of an ALD was beneficial in the Quiet condition, and always offered a benefit over the use of hearing aids alone whether measured by Speech scores (Fig.3). Not using a hearing aid offered better performance than that seen when a hearing aid was used without an ALD. However, the use of ALDs increased the number of correctly identified words compared to the use of a hearing aid alone and was generally either better or comparable to the number identified when no hearing aid was used. Performance always reached a mean score of at least 80%, and reached 97% when the Smartlink was used.

As anticipated, the VAS scores showed a similar trend to those of the CVC speech scores. Using the hearing aid alone, subjects reported hearing the phone marginally better than without the hearing aid, and to the same degree as when the Artone was used. Mean ratings ranged from 6.5 to 8.5, with the worst rating being for non-assisted hearing, and the best being for the Smartlink and iCom, with the Eli just behind.

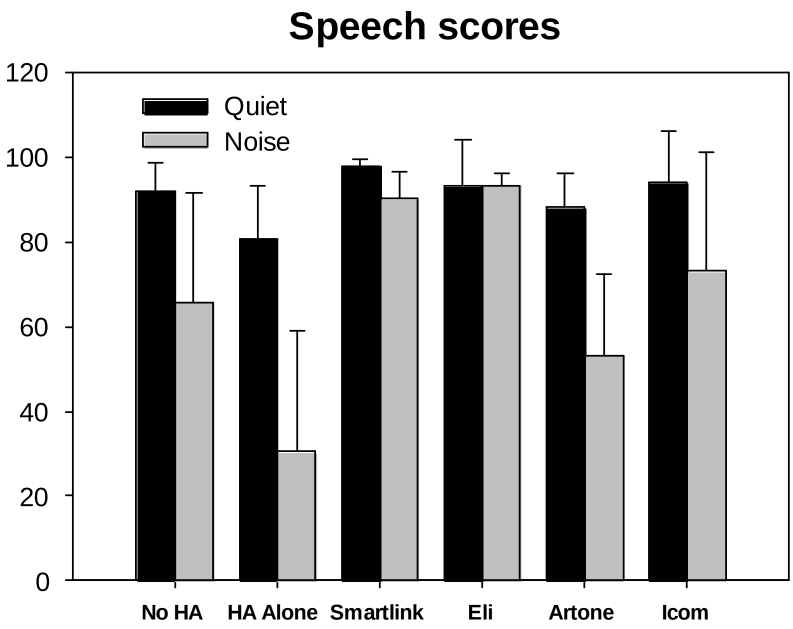


**Figure 3 - Mean CVC speech scores across listeners for each ALD in quiet and noise. The error bars indicate + 1 standard deviation.**

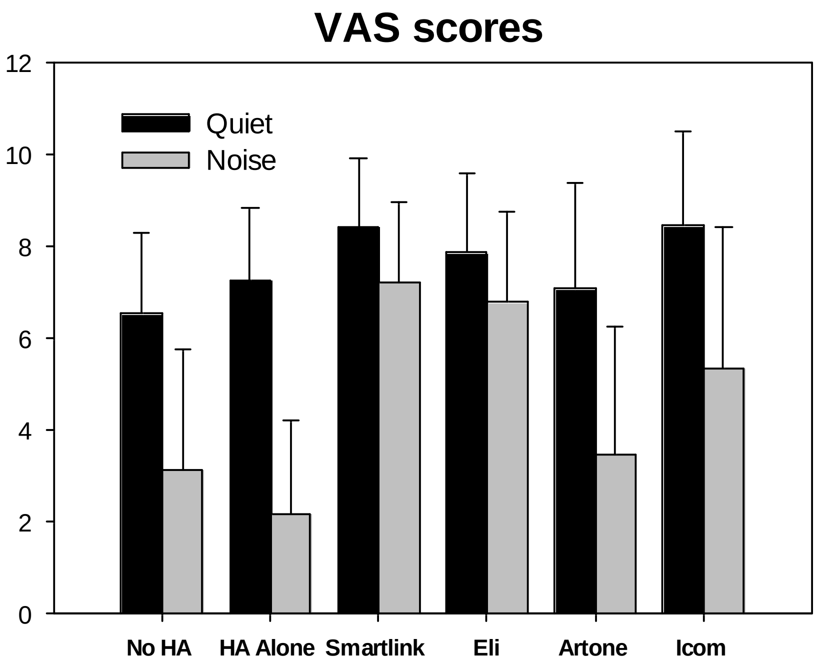


**Figure 4 - Mean VAS (1-10) scores across participants in quiet and noise for each device used. The error bars indicate + 1 standard deviation**

### 3.3.2. Testing in Noise

Unaided speech scores decreased greatly upon addition of background noise, as did those of the hearing aid alone condition. This decrease in performance was recognised by the participants, and the VAS scores changed accordingly. Generally, speech performance in Noise was variable between subjects, as evidenced by the large standard deviation in figure 3.

**Table 1 - General aspects of each ALD which may influence selection**

| | ELI | | Artone | | iCom | | Smart Link | |
|---|---|---|---|---|---|---|---|---|
| **Aesthetic** | No one wanted to wear it | | Good aesthetics; discreet. | | Good aesthetics, feels light and small. | | Good aesthetics but large | |
| **Compatibility** | Any BTE with DAI capabilities | | Any aid with a T coil | | Only Phonak | | Any BTE with FM capabilities | |
| **Usability** | Easy | | Easy | | Easy | | More complicated but no one had any problems | |
| **Size** | Makes HA very large, but no need for other units. | | Good, but has to be worn around the neck | | Good, but has to be worn around neck | | Larger and heavier than the other devices | |
| **Performance in Quiet Ranking** | VAS | Speech | VAS | Speech | VAS | Speech | VAS | Speech |
| **(Average overall score)** | 3rd | 2nd | 4th | 4th | 1st | 3rd | 2nd | 1st |
| **Performance in Noise Ranking** | VAS | Speech | VAS | Speech | VAS | Speech | VAS | Speech |
| **(Average overall score)** | 2nd | 1st | 4th | 4th | 3rd | 3rd | 1st | 2nd |
| **Cost** | Discontinued | | NZ$335.67 | | NZ$337.50 | | NZ$1378.13 | |

The worst performances were seen when in the hearing aid alone and the Artone conditions, with scores of 35% and 50% respectively. However, nearly all participants had a substantial speech benefit from using any of the other ALDs, and the Eli, Smartlink and iCom each reached intelligibility of more than 80%. Comparable VAS scores were obtained in noise when no hearing aid was used, with the hearing aid alone, and when the hearing aid was used in conjunction with the Artone. In these cases, the VAS scores were low (mean <4). The Smartlink and the Eli had the most impact (VAS scores >7), with the iCom also providing subjective improvement (VAS score 5.4).

Performance is, unfortunately, not the only criterion that a user will base their purchase choice on, and other aspects which may play a part are indicated in Table. 1. For example, although the Smartlink offers the best performance, it is also the most expensive and heaviest of the ALDs on test, and this may mean that a user will be less inclined to use it, despite its improved performance over the other choices.

## 4. Discussion

As anticipated, both speech scores and VAS scores reflect the increased difficulty that participants had in hearing in the presence of background noise. It is of interest that speech scores in quiet were actually better without the use of the hearing aid. This could be due to the participants' unfamiliarity with the particular hearing aids used in this study, and despite being instructed as to where to hold the phone relative to the aid's microphone prior to each list being read, this may not have been achieved accurately. Furthermore, previous research has also found evidence that, in noise, unaided listening can provide more satisfactory performance than that seen when the hearing aid was used (Palmer, Bentler, & Mueller, 2006). These authors used annoyance and aversion levels when using either 'Dinner table' or 'traffic' noise, and found that amplification via hearing aids increased both of the studied measures, up to a level that was equal to normal hearing individuals. Annoyance levels were not taken in the current study, but the amplification of the noise, and therefore decrease in the signal to noise ratio, may explain the poorer performance when hearing aids were used over when no amplification was applied.

Overall, the worst performance in both Quiet and Noise conditions was seen with the Artone. Indeed, this device offered little benefit over unaided listening, whether measured objectively via the CVC word recognition scores, or subjectively via the VAS ratings. There were, however, exceptions to this rule, and one listener claimed that 'for looks and function the Artone is the best', despite receiving a higher VAS score when using the Eli device. This may be due to the participant's preference for the aesthetics over function, as the Eli device was consistently deemed to be the most unattractive of the devices tested.

Aside from the measures reported above, subjects were encouraged to make further comments about the devices. Generally, listeners found that the Smartlink had very good performance in quiet ('The best hands down. A bit heavy but worth it') and noise ('Very good: cancelled noise out completely'). As noted above, the Eli was generally not well received due to its appearance, however, performance was generally indicated as being good, although five of the nine participants indicated issues with 'static' in quiet. In noise, the Eli was generally well accepted ('great' and 'the best in noise possibly'). Although speech recognition and VAS scores were low when the Artone was used, the main complaint from users was that it was too soft ('Clear, quite good. Needs to be louder') and when noise was applied, it was inaudible ('Background noise drowns it out'). This may have been remedied by turning up the T coil program on the aid, but as this study was looking at first fit on each device they were all tested in the same situation. Similarly, despite showing promising performance when measured by VAS and speech scores, the iCom was said to be very quiet, and ineffective in noise ('couldn't hear anything in noise'). It should also be noted that the hearing aids used in this study were made by Phonak, and therefore the two ALDs that are also manufactured by this company (Smartlink and iCom) may have benefitted from increased compatibility.

In conclusion, it is apparent that the Smartlink was the most effective assisted listening device used in this trial, both in terms of objective performance, and each listener's view of its functionality. That said, this device was also the most expensive in the test, and this should be taken into account when providing advice to hearing aid users. Individual preference for pricing and aesthetics will also have their part to play in ALD selection, and clinicians may find a trade-off between the latter and functionality.

## 5. Acknowledgements

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